

# Astronomy/Observations in the LISA Timeframe

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LISA 6, GSFC

# Plan

- Multi-wavelength science from LISA
- Ground- and Space-Based Observatories
- White Dwarf Binaries

# **“The LISA Timeframe”**

- This Year
- Next Year
- Sometime
- Never

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**2016???**

# LISA Goals

- To detect gravitational radiation
  - LIGO et al ought to get there first but...
- To observe white dwarf binaries
  - Prosaic but still interesting astrophysically
- To detect the stochastic background
  - Unresolved sources, cosmological?
- To find compact objects orbiting million solar mass black holes.
  - Observe inspirals to check GR
- To watch million solar mass black holes merge
  - Test strong GR. EM harbingers, afterglows
- To find something completely unanticipated
  - “Antimatter stars falling onto white holes”, colliding branes...<sup>4</sup>

# Gravity Power

- $P \sim (G/c^5)Q'''^2 \rightarrow c^5/G$ 
  - $\sim 10^{52.5} W$
  - $\sim 10^{26} L_{\text{sun}}$
  - $\sim 10^{16} L_{\text{gal}}$
  - $\Rightarrow M \sim -60$
  - $\Rightarrow \sim E \text{Jy} \dots$
- $\times$  numbers
- $\times (m/M)^2 ?$
- $\times f_{\text{EM}} ??$
- $\times (M/T) ???$

# Harbingers & Afterglows

- Can you identify imminent, major coalescences of million solar mass holes?
  - Period and phase??
- Can you detect afterglows?
  - Relativistic blast waves??
- Search whole EM spectrum
- Search square degrees?

# Are Mergers EM Bombs?

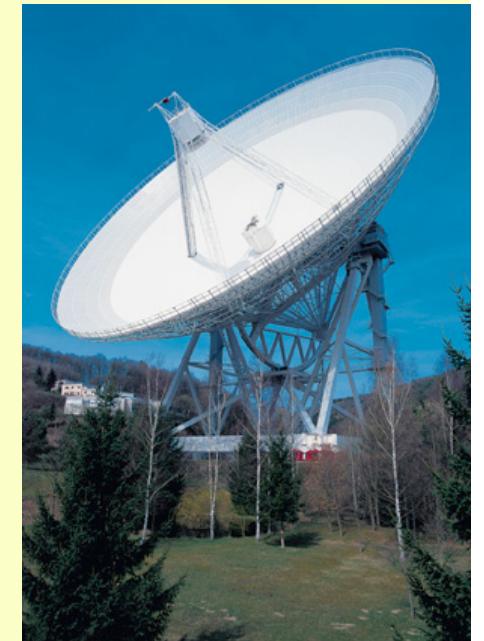
- 2(3) sphere dynamos in force-free electrodynamics
- Magnetic field grows exponentially
- Event horizon provides dissipative load
- Does growth exceed decay for long enough to be interesting?

# Non-*GW* telescopes

- No HST, Chandra, Spitzer, XMM...
- New space and ground-based facilities
- Phasing and competition?

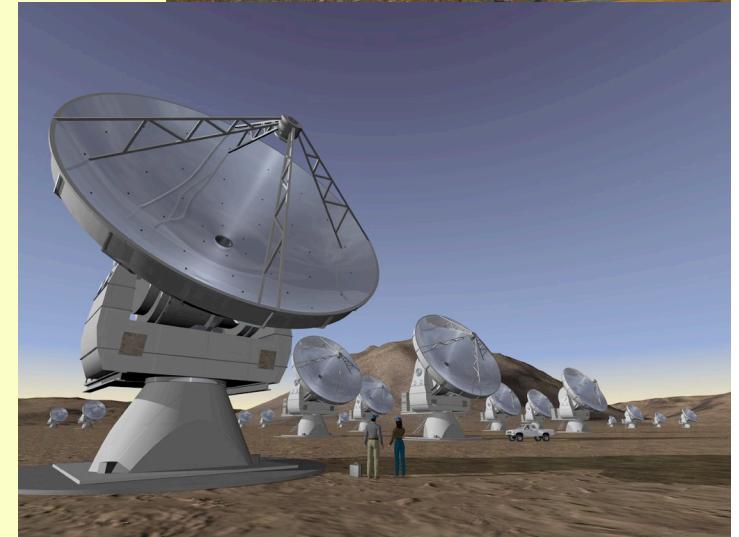
# Single radio dishes

- Arecibo 0.1 sq km not steerable
- Bonn 0.01 sq km
- GBT 0.01 sq km



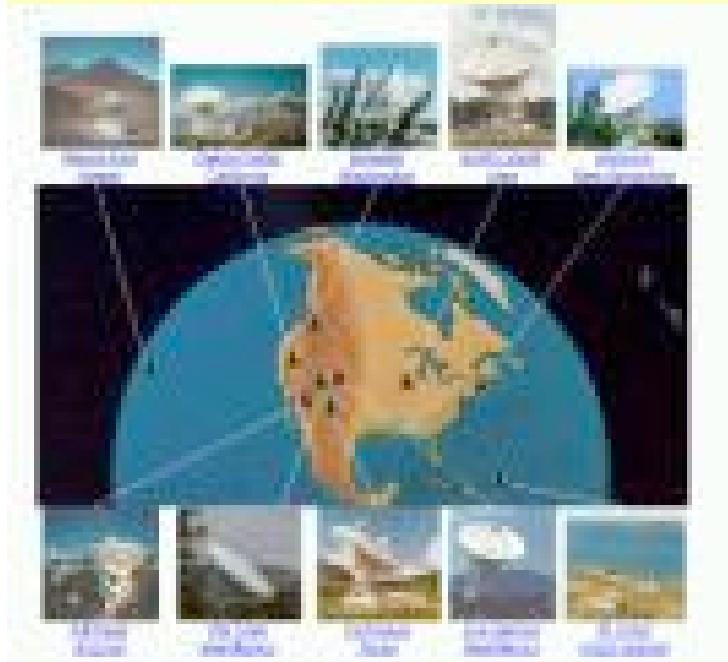
# RMS Interferometers

- VLA
- Australia Telescope
- ALMA (2011)
- SKA precursors
  - LOFAR
  - MWA
- SKA (2019?)
  - Lo/Hi?

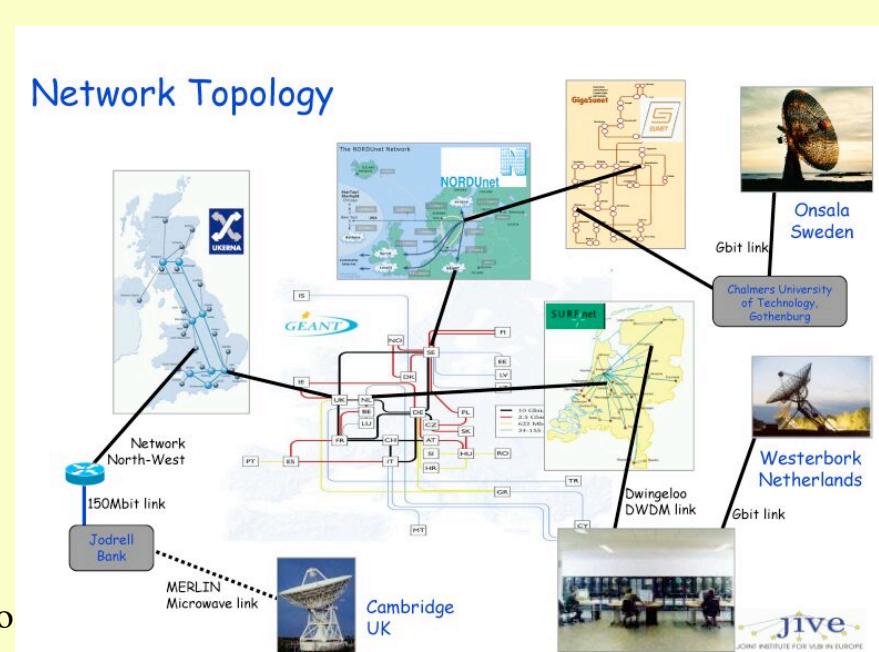


# VLBI

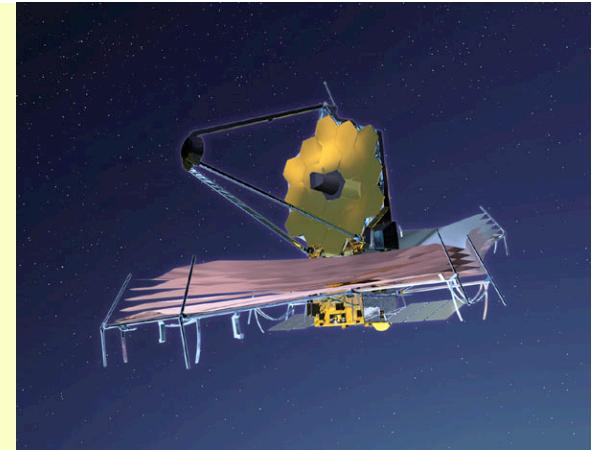
- VLBA 10 station
- European VLBI network
- VSOP2
- 100 $\mu$ as resolution



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# JWST



- 6.5 m infrared telescope
- 2013 launch?
- MIRI 5-27 $\mu$
- FGS
- NIRCAM 0.6-5 $\mu$
- NIRSPEC 0.6-5 $\mu$

# Existing >8m Optical Telescopes

- VLT, Keck, Gemini, Magellan, HET, LBT...



A Symp

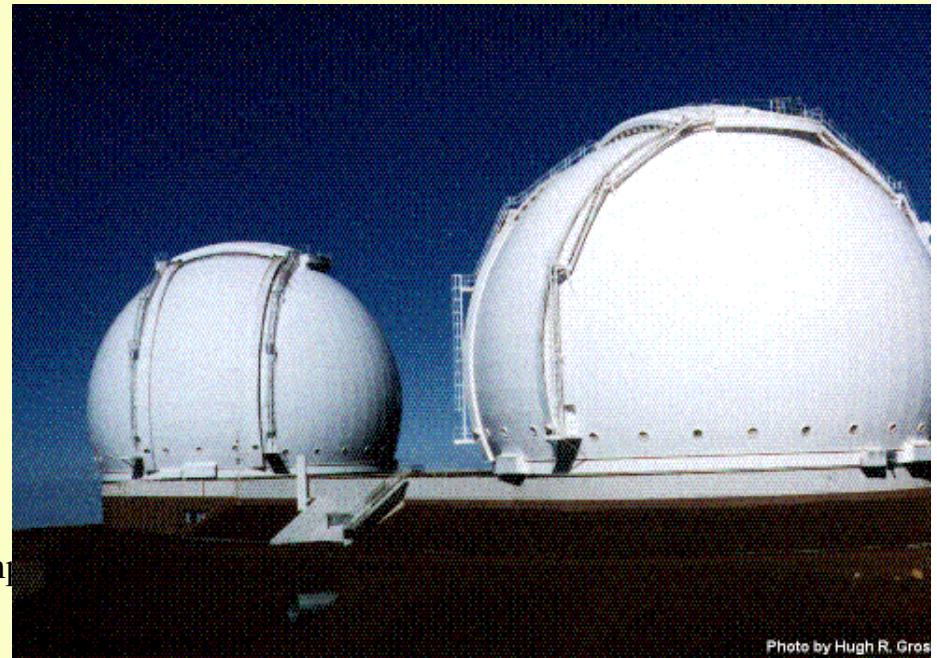


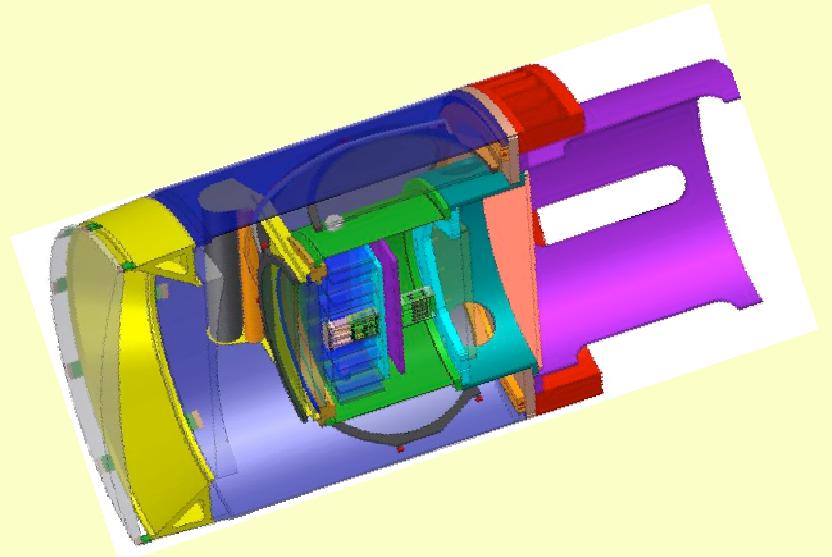
Photo by Hugh R. Gros

# **GSMT**

- In US,
  - TMT = 30m telescope
  - GMT= 20m telescope
- In Europe,
  - OWL = 100m-> 65m->??m telescope
- >2015

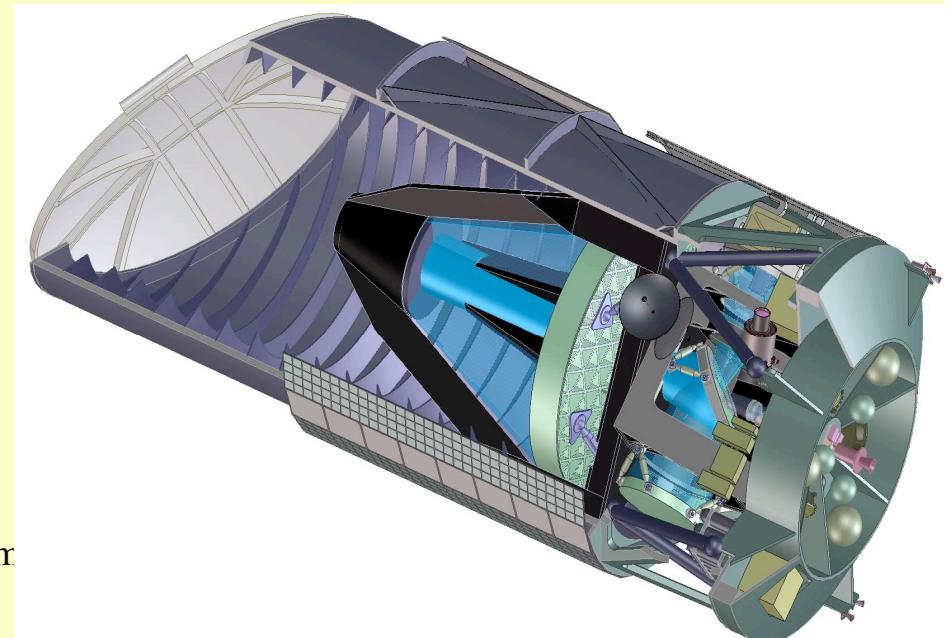
# Wide field survey telescopes LST

- LSST
  - 6m telescope 10sd FOV half sky every 4d
  - 10-15s images 2s readout
  - $A\Omega t > 3000$
  - 2013?
- Pan STARRS – 4
  - 2009?



# JDEM

- Primary goal to study dark energy
- One contender is SNAP
  - Will examine 300sd
  - Wide field survey



# Con-X, XEUS



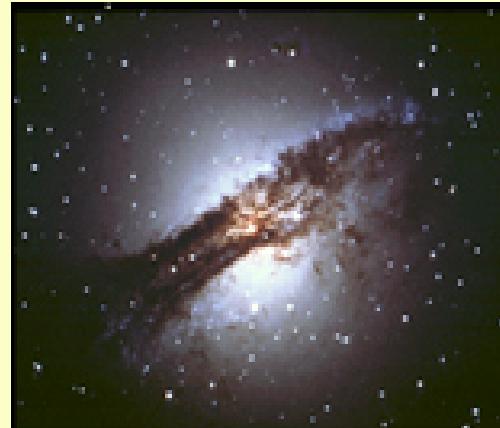
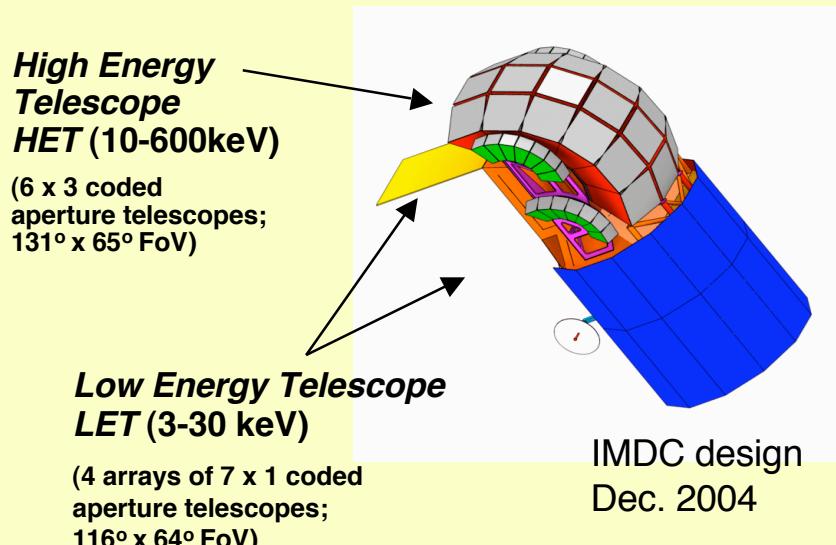
- **Con-X**
  - 0.1-1 sq m.
  - 0.25->10keV-40keV
  - ~1eV resolution
  - 5-15'' resolution
- **XEUS**
  - More ambitious!



# Overview of *BHFP-EXIST* Science and Design

**Hard X-ray (~3-600 keV) all-sky imaging *each orbit* to measure:**

- Obscured AGN and accretion (BHs) vs. nuclear (stars) luminosity of universe
- GRBs out to  $z \sim 20$  and first stellar Black Holes ( $\sim 5X$  *Swift* sensitivity)
- Stellar Black Holes in Galaxy & IMBHs in Local Group & BHs as probes

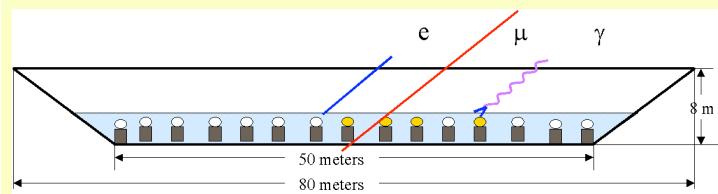
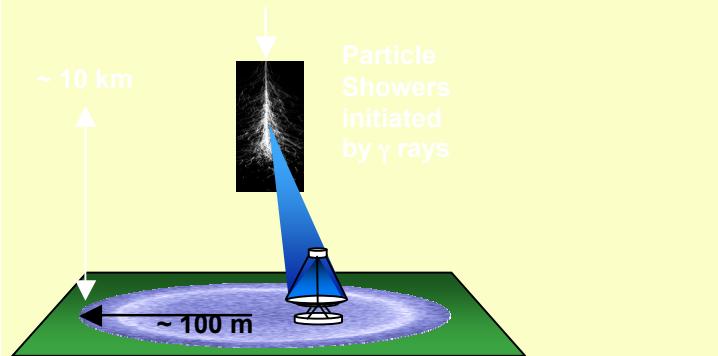
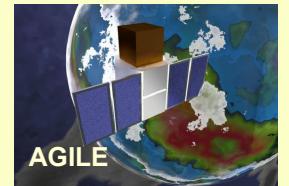
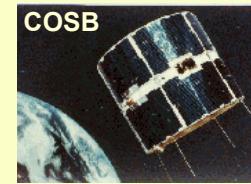
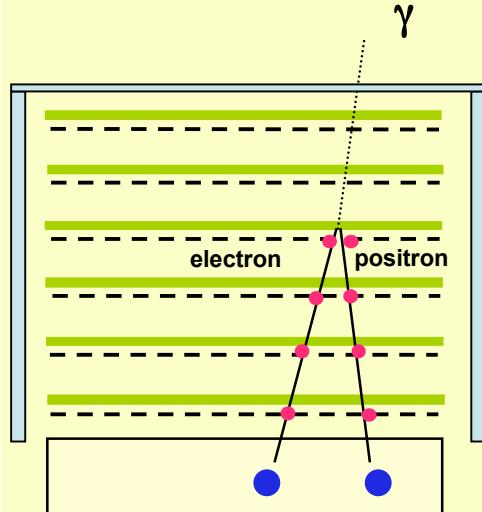


e.g., EXIST measures Cen-A every orbit:  
characteristic time variability (QPOs)  
constrain BH mass

## ***Mission Design parameters:***

- Extend ROSAT sens. ( $\sim 5 \times 10^{-13}$  cgs) to 3-150 keV with 0.9-5' resolution &  $\sim 10''$  positions
- Two wide-field coded aperture telescopes: 10-600 keV ( $6m^2$  CZT) & 3-30 keV ( $1m^2$  Si)

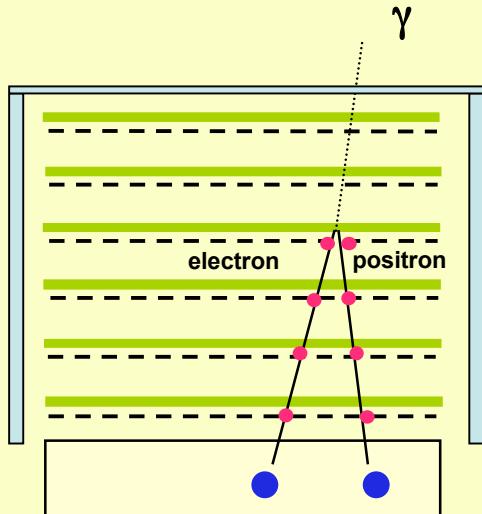
# Gamma Ray Detection Techniques



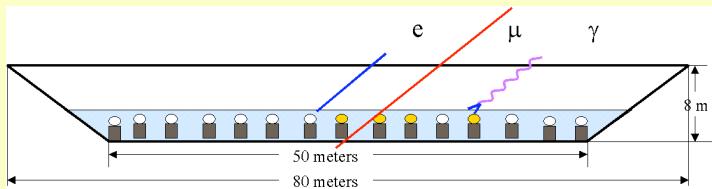
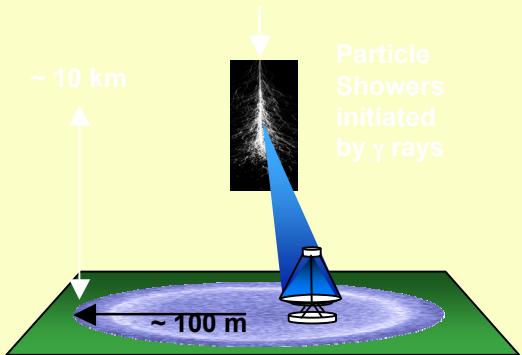
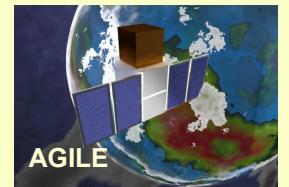
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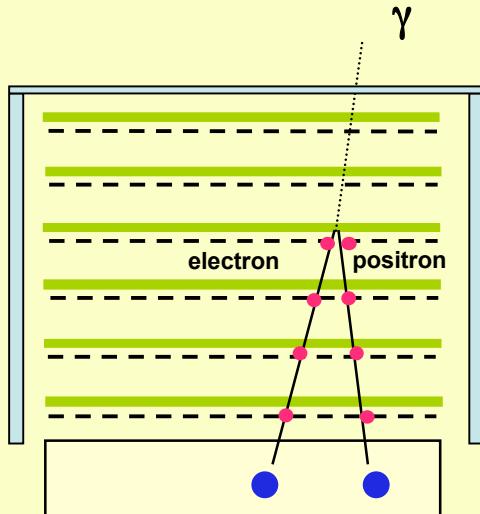
GLAST  
silicon detectors 2007 to ?  
20 MeV to > 300 GeV  
~100 Million  $\gamma$  rays per year



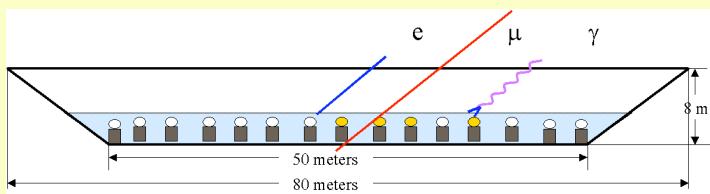
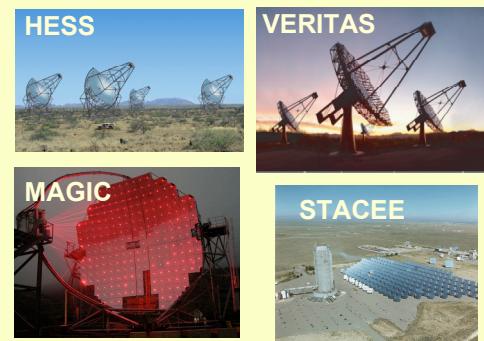
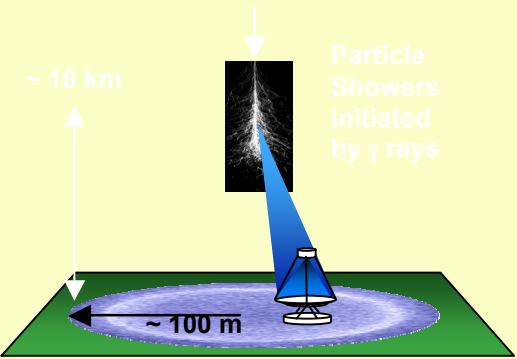
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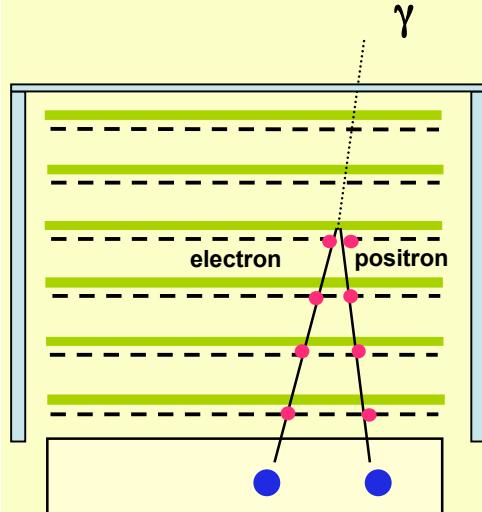


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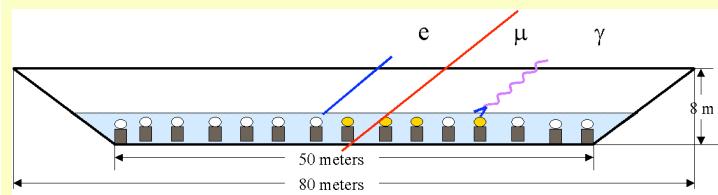
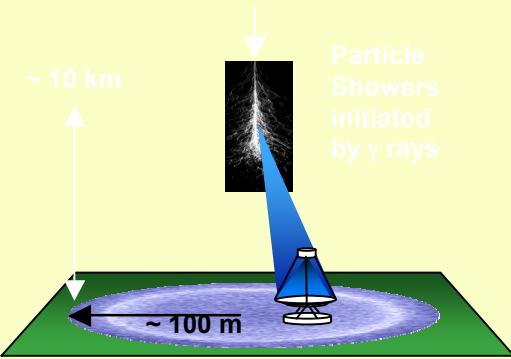
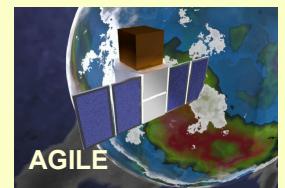
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# Gamma Ray Detection Techniques



GLAST

silicon detectors 2007 to ?  
20 MeV to > 300 GeV  
~100 Million  $\gamma$  rays per year



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# GLAST

GLAST will measure the direction, energy and arrival time of celestial  $\gamma$  rays

Principal Investigator: Peter Michelson

**LAT**  
will record gamma-rays  
in the energy range  
 $\sim 20$  MeV to  $>300$  GeV

**GBM**  
will provide correlative  
observations of transient  
events in the energy  
range  
 $\sim 10$  keV –  $25$  MeV

**Observing modes**  
All sky survey  
Pointed observations

**Re-pointing Capabilities**  
Autonomous  
Rapid slew speed  
( $75^\circ$  in  $< 10$  minutes)



**Orbit**  
565 km, circular

**Inclination**  
 $28.5^\circ$

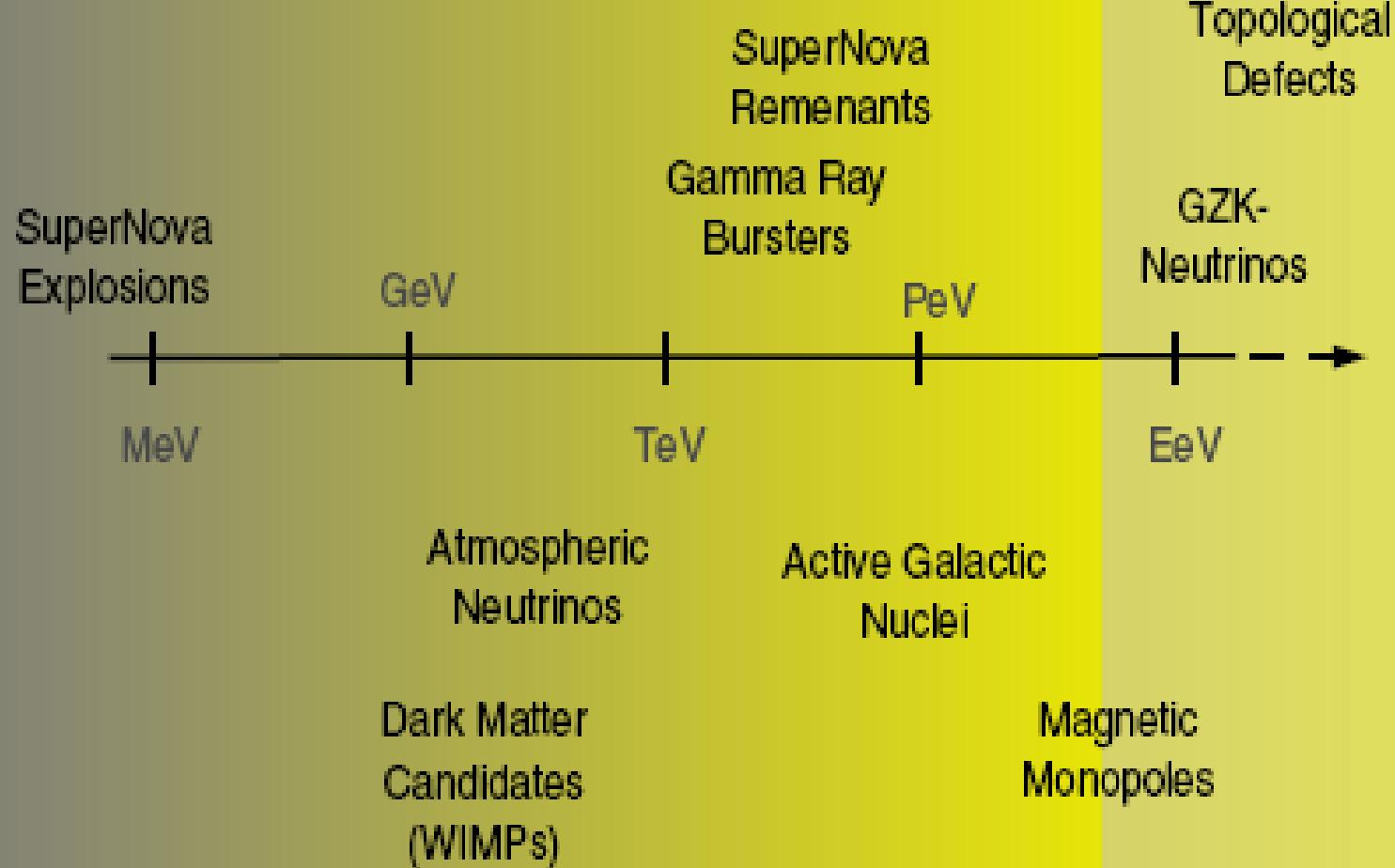
**Lifetime**  
5 years (min)

**Launch Date**  
Sep 2007

**Launch Vehicle**  
Delta 2920H-10

**Launch Site**  
Kennedy Space Center

## High Energy Phenomena for Neutrino Telescopes



# Neutrino Telescopes

## AMANDA-II

New South Pole Station

First **IceCube** string

IceCube Laboratory

1400m

2400m

1500 m

**AMANDA**

2000 m

[not to scale]

## The IceCube Detector

A cubic kilometer of ice instrumented with:

- 80 Strings (9 deployed)
- 4800 Digital Optical Modules
- 17m between Modules
- 125m between Strings

Plus an Air-Shower Array:

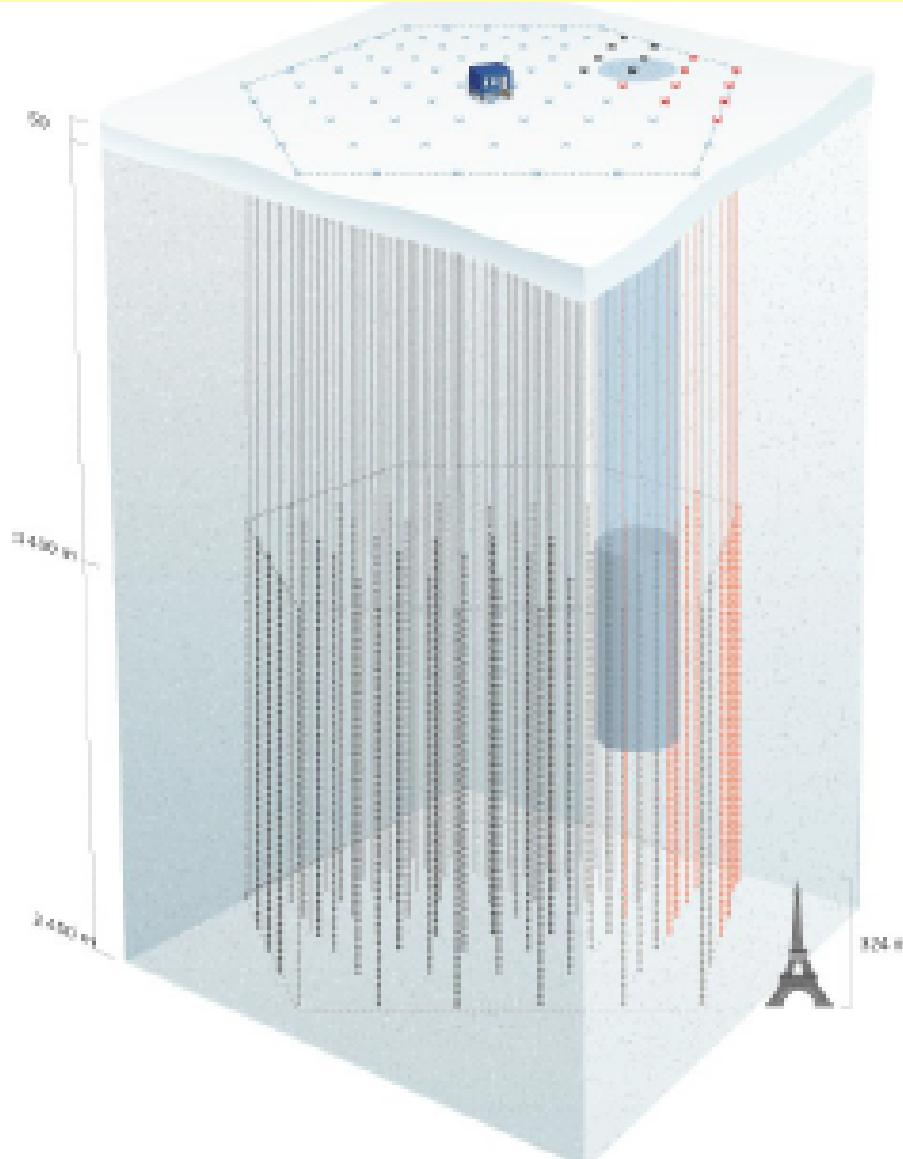
- 80 Pairs of ice-tanks

Includes AMANDA:

- 19 Strings
- 677 Optical Modules

Possible Future Extension:

- 10km x 10km Radio- and Acoustic Array



❖ A Neutrino Observatory at South Pole

# Neutrino Telescopes

# Sky coverage

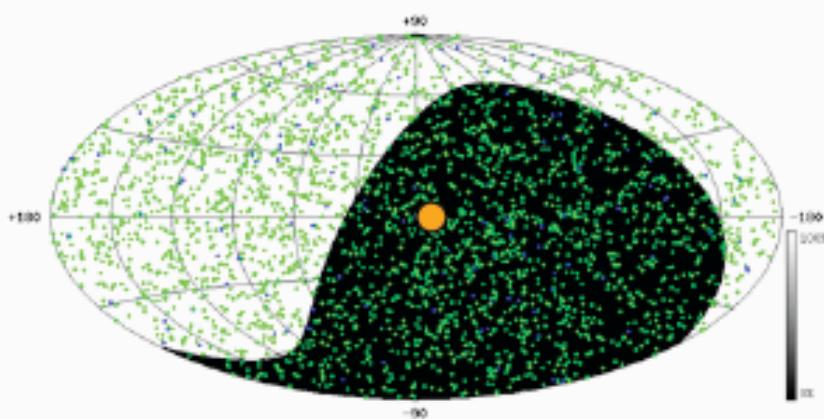
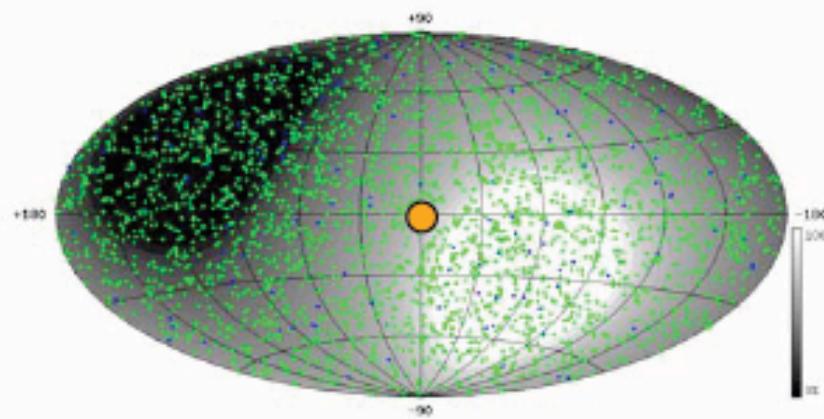
Need earth as shielding against cosmic rays for  $\nu_\mu$  (if  $E_\mu \approx 100$  TeV)

Mediterranean (ocean)

ANTARES, Nestor, NEMO, KM3Net ...

South Pole (ice)

AMANDA, ICECUBE



● galactic center in middle

KARLE TAUP2005

4  $\pi$  coverage for  $\nu_e$ ,  $\nu_\tau$  !

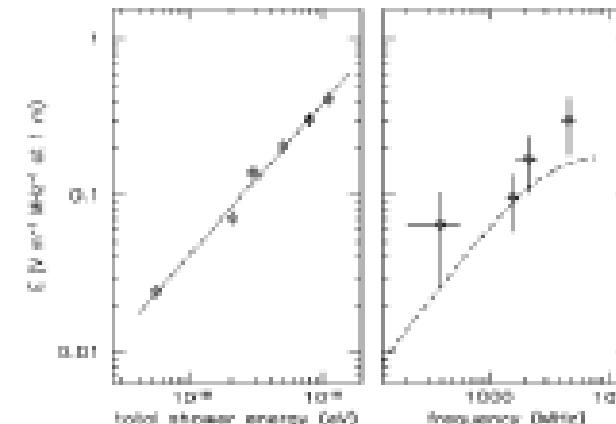
# Radio detection - The Askaryan effect

- Neutrino interaction in dense material creates a cascading shower
- Secondary scattering in the material...

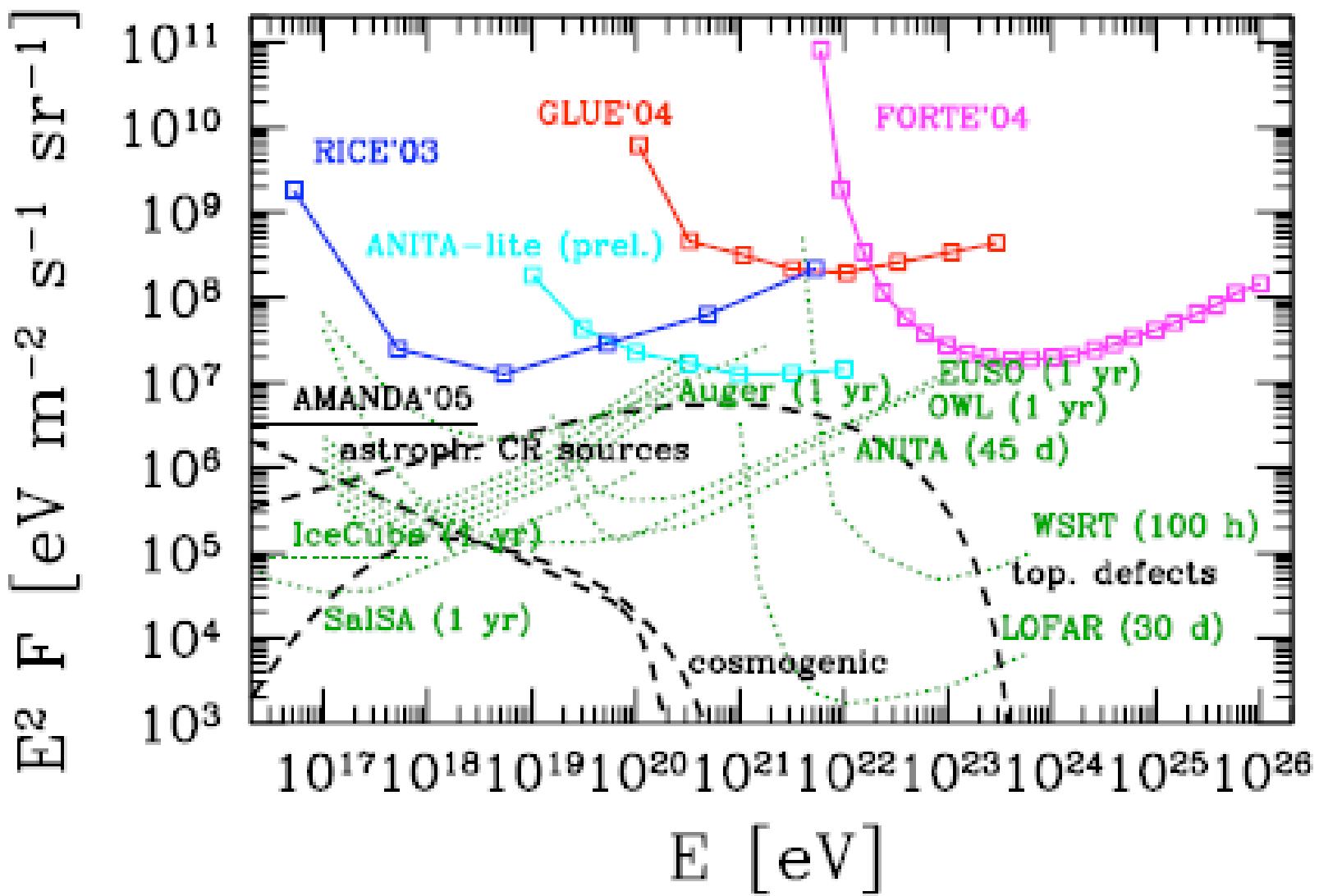


...leads to a negative charge excess of 20-30 %

- Čerenkov emission coherent at wavelengths longer than the transverse dimension of the shower,  $r_M \sim 10 \text{ cm}$
- Predicted by Askaryan in 1962, verified at SLAC in 2001



[Salzberg et al., Phys. Rev. Lett. 85 \(2001\)](#)



For the highest energies: radio detection  
of neutrinos interacting in polar ice, moon,  
salt domes....

# Resonant Excitation of WD Oscillations (Rathore, Broderick, RB)

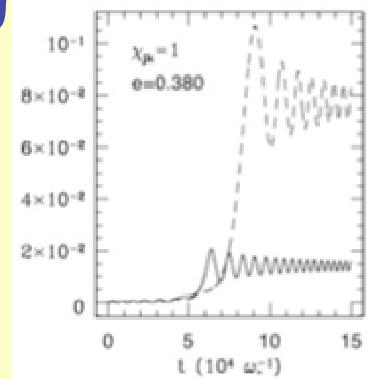
- WD orbiting compact object will pass through resonances between subharmonics of fundamental modes and orbital frequency
  - f-modes  $\sim$ 80 mHz
  - Roche frequency  $\sim$ 30mHz
  - Interaction  $\sim e^2$
  - g-modes for circular orbits
- Orbital energy  $>>$  WD binding energy
  - What is dynamical interaction?
  - Linear model with orbit fixed  $\Rightarrow$  large energy transfer

# Inclusion of back reaction (Rathore)

- Canonical transformations -> 2df system (prograde and retrograde waves)
- Invariant submanifold => Integrable system
- Adiabatic invariance of action variable
- Quantify effects of resonance crossing
- Only f-modes, no rotation
- Influence on waveforms?

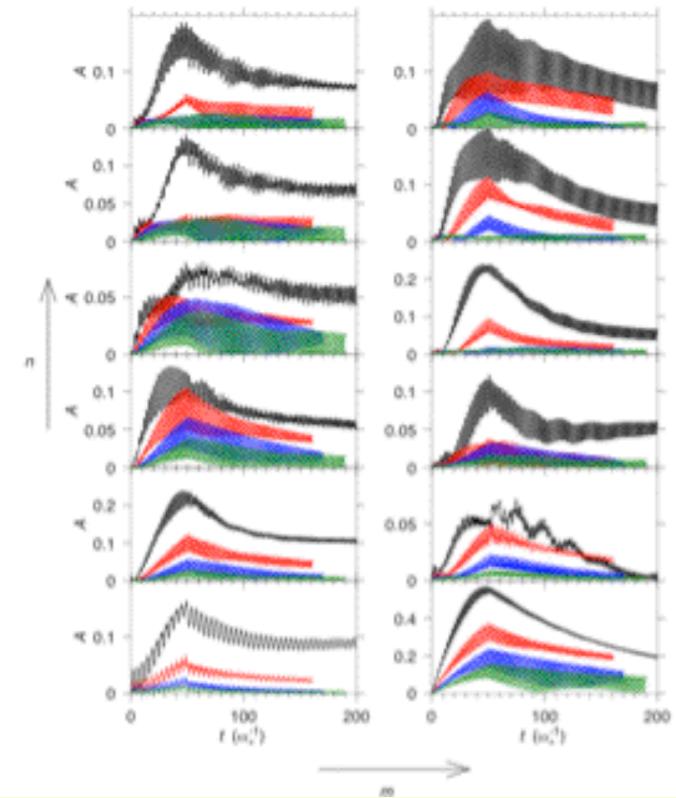
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# Nonlinear waves

- Numerical excitation of
- driven waves
- Do they break?
- No
- What is damping rate between resonances?
- Can you initiate thermal detonation?
  - Strange supernova with trapped debris
  - Not for WD-WD binaries



# Summary

- If and when LISA is able to identify imminent major coalescences of massive holes there will be widefield searches for harbingers
- Post-coalescence afterglows will also be sought eg for relativistic blast waves with ancillary observations.
- White dwarf signal/noise may be interesting astrophysically and for GR.
- **GOOD LUCK!**